DESCRIPTION

DECODING APPARATUS AND DECODING METHOD

5　Technical Field

[0001]　The present invention relates to a decoding apparatus and a decoding method, and is suitable for application in, for example, a decoding apparatus and a decoding method performing turbo decoding.

10

Background Art

[0002]　In recent years, VSF-OFCDM(Variable Spreading Factor-Orthogonal Frequency and Code Division Multiplexing) draws attention as the most likely
15　candidate for the scheme adopted for the fourth generation mobile communication.　If VSF-OFCDM is employed, it will be possible to realize a maximum transmission rate of 100Mbps or more using bandwidth of about 50-100MHz.　It is effective to employ turbo coding/decoding as an error
20　correction scheme for such an ultra high-speed transmission scheme.

[0003]　The turbo coding/decoding scheme is characterized by using both convolutional coding and interleaving for transmission data and performing
25　iterative decoding upon decoding.　It is well known that performing iterative decoding achieves excellent error correction capability not only for random errors, but

for burst errors.

[0004] Here, an algorithm of turbo decoding will be explained briefly using equations. With turbo decoding, likelihood information $L(d_k)$ is calculated, and calculated likelihood information $L(d_k)$ is compared with a threshold value "0." As a result of the comparison, when likelihood information $L(d_k)$ is "0" or more, a hard decision is made that the systematic bit $d_k = 1$ transmitted at time k. When likelihood information $L(d_k)$ is less than "0," a hard decision is made that the systematic bit $d_k = 0$ transmitted at time k.

[0005] Here, likelihood information $L(d_k)$ will be explained. Likelihood information $L(d_k)$ can be represented by the following equation using probability λ_k that is defined as a product of forward probability α_k and backward probability β_k.

[0006]

(Equation 1)

$$L(d_k) = \log \frac{\sum_m \lambda_k^1(m)}{\sum_m \lambda_k^0(m)} \quad \text{...}(1)$$

[0007]

(Equation 2)

$$\lambda_k^i = \alpha_k(m) \cdot \beta_k(m) \quad \text{...}(2)$$

m is the state in a state transition trellis. Forward probability α_k and backward probability β_k can be represented by the following equations respectively.

[0008]

(Equation 3)

$$\alpha_k(m) = \frac{\displaystyle\sum_{m'}\sum_{i=0}^{1}\gamma_i(R_k,m',m)\alpha_{k-1}(m')}{\displaystyle\sum_{m}\sum_{m'}\sum_{i=0}^{1}\gamma_i(R_k,m',m)\alpha_{k-1}(m')} \qquad \ldots(3)$$

[0009]

(Equation 4)

$$\beta_k(m) = \frac{\displaystyle\sum_{m'}\sum_{i=0}^{1}\gamma_i(R_{k+1},m',m)\beta_{k+1}(m')}{\displaystyle\sum_{m}\sum_{m'}\sum_{i=0}^{1}\gamma_i(R_{k+1},m,m')\alpha_k(m')} \qquad \ldots(4)$$

m' is also the state in a state transition trellis, and a transition probability γ_i can be represented by the following equation.

[0010]

(Equation 5)

$$\gamma_i(R_k,m',m) = p(R_k/d_k = i, S_k = m, S_{k-1} = m')$$
$$\cdot q(d_k = i/S_k = m, S_{k-1} = m') \cdot \pi(S_k = m/S_{k-1} = m') \qquad \ldots(5)$$

Here, R_k is an input to a decoder at time k, and $p(\cdot/\cdot)$ is the transition probability of the discrete Gaussian memoryless transmission path. In addition, q corresponds to 0 or 1, and π represents a state transition probability of the trellis.

[0011] With turbo decoding, information bit d_k is decoded by performing the above-noted calculation, which, however, requires an enormous memory capacity. Then, a method called the sliding window method is considered.

[0012] Using this sliding window method makes possible

considerable reduction in memory capacity. Turbo decoding processing procedures are, as described above, generally divided into the calculation of forward probability α (hereinafter referred to as "A

5   calculation"), the calculation of backward probability β (hereinafter referred to as "B calculation") and the calculation of likelihood information $L(d_k)$. The sliding window method is a method that effectively performs the A calculation and B calculation.

10   [0013] In the following, the sliding window method will be explained. The sliding window method divides all sequences of data into predetermined window units, provides a training interval for each window and calculates the backward probability, which must be

15   calculated from the end of the sequences, from the middle of the sequences. According to this sliding window method, it is only necessary to store the backward probability on a per window basis, so that it is possible to considerably reduce memory capacity, compared to the case

20   of storing all backward probabilities of times k to 1.
[0014] Here, more specifically, the sliding window method in case of performing the B calculation will be explained with reference to an accompanying drawing. FIG.1 is a pattern diagram conceptually showing

25   repetition processing of conventional B calculation. Here, an explanation will be provided making the window size 32 and using three windows for ease of explanation.

In this figure, the window at time 0-31 is B#0, the window at time 32-63 is B#1 and the window at time 64-95 is B#2. In addition, since the B calculation performs the calculation in backward direction in time, the training interval is put at the last time of each window and generally is four or five times longer than the constraint length.

[0015]   Repetition processing of conventional B calculation initializes the initial value of each training interval to "0" for each iterative decoding and performs calculation using reliability information of each window obtained in previous decoding processing.

Non-Patent Document 1:   Claude Berrou, "Near Optimum Error Correcting Coding And Decoding: Turbo-Codes," IEEE Trans. On Communications, Vol.44, No10, Oct. 1996.

Disclosure of Invention
Problems to be Solved by the Invention
[0016]   However, since conventional sliding window method has a long training interval, there is a problem that the calculation amount and memory capacity of a turbo decoder are large. In addition, since the length of the training interval is fixed, there is a possibility that deterioration of characteristic worsens as the coding rate increases, and there is a problem that the training interval must be long in order to maintain the

characteristic.

[0017]   It is therefore an object of the present invention to provide a decoding apparatus and a decoding method that reduce the calculation amount and memory capacity and prevent deterioration of characteristic at high coding rates.

Means for Solving the Problems

[0018]   The decoding apparatus of the present invention employs a configuration having: a backward probability calculation section that divides a data sequence into a plurality of windows and calculates a backward probability per window using a backward probability at a predetermined time calculated in previous iterative decoding as an initial value in iterative decoding of this time; a storage section that stores the backward probability at predetermined time calculated by the backward probability calculation section; and a likelihood calculation section that calculates likelihood information using the backward probability calculated by the backward probability calculation section.

Advantageous Effect of the Invention

[0019]   With the present invention, the backward probability is calculated using the backward probability at a predetermined time calculated in previous iterative

decoding as the initial value for iterative decoding of this time, so that characteristic can be improved even when the training interval is short, and it is therefore possible to reduce the calculation amount and memory

5 capacity and prevent deterioration of characteristic at high coding rates.

Brief Description of the Drawings
[0020]

10   FIG.1 is a pattern diagram conceptually showing the repetition processing of conventional B calculation;

FIG.2 is a block diagram showing the configuration of the turbo decoder according to Embodiment 1 of the present invention;

15   FIG.3 is a block diagram showing the internal configuration of the element decoder;

FIG.4 is a pattern diagram conceptually showing the repetition processing of B calculation according to Embodiment 1 of the present invention;

20   FIG.5 is a diagram showing the decoding characteristic of the turbo decoder according to Embodiment 1 of the present invention; and

FIG.6 is a pattern diagram conceptually showing the repetition processing of B calculation according to

25 Embodiment 2 of the present invention.

Best Mode for Carrying Out the Invention

[0021]   Embodiments of the present invention will be explained below in detail with reference to the accompanying drawings.

[0022]   (Embodiment 1)

FIG.2 is a block diagram showing a configuration of a turbo decoder according to Embodiment 1 of the present invention.   In this figure, element decoder 101 executes decoding processing on systematic bit sequence Y1 and parity bit sequence Y2 with a priori value La1, which is reliability information transmitted from deinterleaver 105, and outputs external value Le1 to interleaver 102.   The external value indicates the increment of reliability by the element decoder.

[0023]   Interleaver 102 rearranges external value Le1 output from element decoder 101 and outputs the result to element decoder 104 as a priori value La2. Incidentally, decoding is not performed at element decoder 104 in the first iteration and therefore "0" is substituted for the a priori value.

[0024]   Element decoder 104 receives as input a sequence in which systematic bit sequences Y1 is rearranged at interleaver 103, parity bit sequence Y3 and a priori value La2, performs decoding processing and outputs external value Le2 to deinterleaver 105.

[0025]   Deinterleaver 105 performs the operation of undoing the rearrangement by the interleaver upon external value Le2 to restore the rearrangement by the

interleaver and outputs the result to element decoder
101 as a priori value La1. By this means, iterative
decoding is performed. After iterative decoding is
performed from several times to over ten times, element

5   decoder 104 calculates posteriori value L2, which is
defined as the logarithmic posteriori probability ratio,
and outputs the calculation result to deinterleaver 106.
Deinterleaver 106 deinterleaves the calculation result
output from element decoder 104 and outputs the

10   deinterleaved sequences to hard decision section 107.
[0026] Hard decision section 107 performs hard decision
with the deinterleaved sequences, thereby outputting
decoded bit sequences. Error detection section 108
performs error detection with the decoded bit sequences

15   and outputs the detection result.
[0027] FIG.3 is a block diagram showing the internal
configuration of element decoder 101. Assume that
element decoder 104 has the same internal configuration
as element decoder 101. Assume that decoding operation

20   described below is performed in a window basis of a
predetermined size.
[0028] First, systematic bit Y1, parity bit Y2 and a
priori value La1 obtained from previous decoding result
are input to transition probability calculation section

25   201, and transition probability γ is calculated. The
calculated transition probability γ is output to forward
probability calculation section 202 and backward

probability calculation section 203.

[0029]   Forward probability calculation section 202
performs the calculation of the above equation (3) with
respect to the data sequence divided for per window using
transition   probability γ output   from   transition
probability   calculation   section   201   and   calculates
forward probability α_k(m). The calculated α_k(m) is output
to likelihood calculation section 205.

[0030]   Backward probability calculation section 203
performs the calculation(B calculation) of the above
equation (4) with respect to data sequence divided per
window using transition probability γ output from
transition probability calculation section 201 and a
value described below that is stored in memory 204, which
will be described later, and calculates backward
probability β_k(m). The calculated backward probability
β_k(m) is output to likelihood calculation section 205.
In addition, backward probability that is used as initial
value for the next iterative decoding is output to memory
204.

[0031]   Memory 204 temporarily stores the backward
probability of a predetermined time that is output from
backward probability calculation section 203 and, when
backward probability calculation section 203 performs
iterative   decoding,   outputs   the   stored   backward
probability of a predetermined time in previous decoding
to backward probability calculation section 203. The

predetermined time corresponds to the time at which the calculation starts in each window, in the next iterative decoding.

[0032] Likelihood calculation section 205 performs the calculation of the above equation (1) using forward probability $\alpha_k(m)$ output from forward probability calculation section 202 and backward probability $\beta_k(m)$ output from backward probability calculation section 203 and calculates likelihood information.

[0033] Next, the sliding window method when B calculation is performed by a turbo decoder will be explained. FIG.4 is a pattern diagram conceptually showing repetition processing of B calculation according to Embodiment 1 of the present invention. Here, an explanation will be provided making the window size 32 and using three windows for ease of explanation. In this figure, in iteration number 1, the window of time 0-31 is B#0, the window of time 32-63 is B#1 and the window of time 64-95 is B#2. In addition, the training interval has a size of four and is put at the last time of each window.

[0034] In the B calculation in iteration number 1, the calculation starts from the training interval of each window and proceeds in backward direction from higher time. Then, the backward probability of time 36 of window B#1 is stored in memory 204 and the backward probability of time 68 of window B#2 is stored in memory 204.

[0035] In iteration number 2, the backward probability

of time 36 stored in memory 204 in iteration number 1

is made the initial value of the training interval of

window B#0 and the backward probability of time 68 stored

in memory 204 is made the initial value of the training

5   interval of window B#1. Thus, by using the backward

probability obtained in previous decoding as the initial

value of this time, it is possible to consider that previous

decoding processing correlates to the training interval

of this time and improve decoding accuracy.

10   [0036] In addition, in iteration number 2, the window

size of window B#0 is made larger by one and the time

is made 0-32. The time of window B#1 and window B#2 is

brought forward by one, and the time of window B#1 is

33-64 and time of window B#2 is 65-96. In line with this,

15   the time of the training interval also changes.

[0037] Assuming that the iteration number is i and

generally represented, the B calculation is performed

using the backward probability at a predetermined time

of iteration number (i-1) as the initial value of the

20   training interval of each window, expanding window B#0

backward by time i and shifting window B#1, B#2 … backward

by time i.

[0038] Next, decoding characteristics when the above

sliding window method is used will be explained. FIG.5

25   is a diagram showing decoding characteristics of a turbo

decoder according to Embodiment 1 of the present invention.

In this figure, the vertical axis is the bit error rate

(BER) and the horizontal axis is Eb/NO. In addition, the solid line indicates decoding characteristics of the turbo decoder according to the embodiment and the dotted line indicates decoding characteristic of a conventional turbo decoder. Simulation parameters are as follows:

[0039]

Modulation scheme (Data): QPSK

Coding rate: 5/6

Spreading factor: 16

Channel model: AWGN (Additive White Gaussian Noise)

Training interval: 32

As can be seen from this figure, the decoding characteristic of the turbo decoder of the embodiment indicated by the solid line is excellent. Here, good decoding characteristic can be obtained although the coding rate is set high at 5/6, so that it is possible to prevent deterioration of characteristic even when the coding rate is high.

[0040] Here, comparison is made with a case when a training interval is 32, however, as described above, the same decoding characteristic as the solid line can be achieved even when the training interval is 4, so that it is possible to prevent deterioration even when the training interval is short.

[0041] Thus, according to the embodiment, the backward probability of a predetermined time of each window in previous decoding is made the initial value of the training

interval of this time, and the window position is shifted

backward each time decoding is iterated, so that the

accuracy of the initial value improves every iteration,

and it is possible to reduce the training interval and

5   reduce the calculation amount and memory capacity. In

addition, it is possible to prevent deterioration of

characteristics at high coding rates.

[0042] (Embodiment 2)

A case will be described with Embodiment 2 of the

10   present invention where the training interval is not

provided. The configuration of the turbo decoder of the

embodiment is the same as that of FIG.2, and the

configuration of the element decoder is the same as that

of FIG.3, and, therefore, FIG 2 and FIG.3 are incorporated

15   by reference and detailed explanations thereof are

omitted.

[0043] FIG.6 is a pattern diagram conceptually showing

the repetition processing of the B calculation according

to Embodiment 2 of the present invention. Here, an

20   explanation will be provided making the window size 32

and using three windows for ease of explanation. In this

figure, in iteration number 1, the window of time 0-31

is B#0, the window of time 32-63 is B#1 and the window

of time 64-95 is B#2.

25   [0044] In the B calculation in iteration number 1, the

calculation is performed from higher time to the backward

direction, and the backward probability at time 32 of

window B#1 is stored in memory 204 and the backward probability at time 64 of window B#2 is stored in memory 204.

[0045] In iteration number 2, the backward probability at time 32 stored in memory 204 in iteration number 1 is made the initial value of the training interval of window B#0 and the backward probability at time 64 stored in memory 204 is made the initial value of the training interval of window B#1. In addition, the window size of window B#0 is made larger by one and the time is made 0-32. The time of window B#1 and window B#2 is brought forward by one, and the time of window B#1 are 33-64 and the time of window B#2 is 65-96.

[0046] Assuming that iteration number is i and generally represented, the B calculation is performed using the backward probability at a predetermined time in iteration number (i-1) as the initial value at the start of operation in each window, expanding window B#0 backward by time i and shifting window B#1, B#2 … backward by time i.

[0047] Decoding characteristics when the above sliding window method is used shows substantially the same characteristic as that indicated by the solid line of FIG.5 of Embodiment 1, and it is possible to prevent deterioration of characteristic without providing the training interval.

[0048] Thus, according to this embodiment, the backward probability of a predetermined time in each window in

previous decoding is made the initial value of the training

interval of this time and the window position is shifted

backward each time decoding is iterated, so that the

accuracy of the initial value improves every iteration,

5   it   is   possible   to   prevent   deterioration   of

characteristics without providing a training interval

and reduce the calculation amount and memory capacity.

[0049]   Although   cases   of   backward   probability

calculation   have   been   described   with   the   above

10   embodiments, the present invention is by no means limited

to this, and it is equally possible to calculate the forward

probability   using   the   forward   probability   of   a

predetermined time   calculated   in   previous   iterative

decoding as the initial value in iterative decoding of

15   this time.   By this means, it is possible to reduce the

training interval used in forward probability calculation

and reduce the calculation amount and memory capacity.

[0050]   In addition, regarding the amount of shifting the

window, cases have been described above with the above

20   embodiments where, when the iteration number is i, a shift

is applied in proportion of time i.   However, the present

invention by no means limited to this, and it is equally

possible to make the shift amount (i-1) × j.   Note that

j is a positive number excluding 0.

25   [0051]   A first aspect of the present invention provides

a decoding   apparatus   having: a   backward   probability

calculation section that divides a data sequence into

a plurality of windows and calculates a backward probability per window using the backward probability at a predetermined time calculated in previous iterative decoding as an initial value in iterative decoding of this time; a storage section that stores the backward probability at a predetermined time calculated by the backward probability calculation section; and, a likelihood calculation section that calculates likelihood information using the backward probability calculated by the backward probability calculation section.

[0052] A second aspect of the present invention provides the decoding apparatus of the above-described aspect in which the backward probability calculation section shifts a window position backward in accordance with a number of iterations of decoding and calculates the backward probability.

[0053] With these configurations, by calculating the backward probability per window using the backward probability at a predetermined time calculated in previous iterative decoding as the initial value in iterative decoding of this time, the accuracy of the initial value improves as the number of iterations grows, so that it is possible to reduce the training interval and reduce the calculation amount and memory capacity. In addition, it is possible to prevent deterioration of characteristics at high coding rates.

[0054]   A third aspect of the present invention provides the decoding apparatus of the above-described aspect in which the storage section stores the backward probability at the time next iterative decoding begins in accordance with the backward shift of the window position by the backward probability calculation section.

[0055]   According to this configuration, in accordance with the backward shift of the window position by the backward probability calculation section, the storage section stores the backward probability at the time the next iterative decoding begins --that is to say, the initial value--so that, even when the window shifts and the calculation start point changes every iteration, the initial value of high accuracy is used, and it is possible to reduce the training interval and reduce the calculation amount and memory capacity.

[0056]   A fourth aspect of the present invention provides the decoding apparatus having: a forward probability calculation section that divides a data sequence into a plurality of windows and calculates a forward probability per window using the forward probability at a predetermined time calculated in previous iterative decoding as an initial value in iterative decoding of this time; a storage section that stores the forward probability at a predetermined time calculated by the forward probability calculation section; and, a likelihood calculation section that calculates

likelihood information using the forward probability calculated by the forward probability calculation section.

[0057] According to this configuration, by calculating a forward probability per window using the forward probability of a predetermined time calculated in previous iterative decoding as the initial value in iterative decoding of this time, the accuracy of the initial value improves as a number of iteration grows, so that it is possible to reduce a training interval and reduce the calculation amount and memory capacity. In addition, it is possible to prevent deterioration of characteristics at high coding rates.

[0058] A fifth aspect of the present invention provides a decoding method in which a data sequence is divided into a plurality of windows and a backward probability is calculated per window using the backward probability at predetermined time calculated in previous iterative decoding as an initial value of iterative decoding of this time.

[0059] With this method, by calculating the backward probability per window using the backward probability at a predetermined time calculated in previous iterative decoding as the initial value in iterative decoding of this time, the accuracy of the initial value improves as the number of iterations grows, so that it is possible to reduce the training interval and reduce the calculation

amount and memory capacity. In addition, it is possible to prevent deterioration of characteristics at high coding rates.

[0060] The present application is based on Japanese Patent Application No.2003-402218, filed on December 1, 2003, the entire content of which is expressly incorporated by reference herein.

Industrial Applicability

[0061] The decoding apparatus of the present invention calculates a backward probability using the backward probability at a predetermined time calculated in previous iterative decoding as initial value in iterative decoding of this time, thereby providing an advantage of reducing the calculation amount and memory capacity and preventing deterioration of characteristics at high coding rates, and is applicable to a turbo decoder and so forth.